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Augmented Reality, a Tool to Enhance Conceptual Understanding for Engineering Students

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***Abstract*-Engineering is a field that requires extensive practical approach of learning along with conceptual understanding of theoretical aspects of the subjects. Students are required to implement theoretical knowledge to practical use as a mandatory part of the curriculum in all the schools globally. A part of this is achieved using various training kits available in laboratories with operating manuals and teachers to assist the students. This paper proposes an interesting way to guide students to use such kits by introducing Augmented Reality (AR) as an interactive user manual, thereby increasing students' interest and ease in learning and reducing work load of lab instructors. The AR application developed here demonstrates making connections, applying inputs and videos of expected outputs of lab equipment when viewed through the camera of a smart phone or a PDA. The app also provides options for selection of a particular task if a kit offers more than one experiments. We have developed the application for the lab work of an entire course of Analog and Digital Communications (ES342) at Mehran University of Engineering and Technology, Pakistan, in Unity 3D using Vuforia Augmented Reality Software Development Kit.**

***Index Terms* — Augmented reality, Engineering, Unity, Vuforia.**

I. INTRODUCTION

Augmented Reality is a rapidly emerging field that deals with the addition of audio, visual, or any other sensory data to the existing reality to enhance the actual scene by superimposing a secondary reality scene. In recent years, AR has emerged as a game-changer technology and proved its versatility in countless fields. The applications of augmented reality started off from medical and military purposes and now they have made their way to numerous disciplines like entertainment, art, education, architecture etc. With the use of powerful mobile devices, it is also being used as a learning aid for students from primary schools to university level. The field of education keeps implementing new trends to advance the methods of teaching. We have used AR technology to develop interactive user guide for lab trainers that are aimed to ease and increase students' hands-on practice on the trainers and reduce instructors' efforts. The application also overcomes the need of the user manuals with long written instructions and the AR environment superimposed on the trainer greatly increases students' interest.The organization of this paper is such that the work related to evolution of AR and related applications is discussed in Section II. Section III provides information of the equipment, algorithm, experimental setup and implementation methodology of AR assisted labs. Section IV evaluates the performance of the developed system and results whereas the paper is concluded in Section V.

II. LITERATURE REVIEW

AR has been used in numerous fields such as engineering design, medicine, military, education, robotics, manufacturing, maintenance and repair applications, consumer design, psychological treatments, training, exercises, games, etc. This section primarily covers the review of AR in education and school learning, along with a brief overview of other applications of AR in modern technology. [1] Examines the effects of a marker-based AR technology to teach science related vocabulary words to college students with Intellectual Disability (ID) and Autism Spectrum Disorder (ASD) using a mobile app providing different AR content viewing experiences. [2] used an AR based video-modeling storybook to strengthen and attract the attention of children with ASD. [3] Discuses AR technologies and suggests that existing books be developed into AR editions after publication, thus making textbooks a dynamic source of information. In this way people with no computer background can still have a rich interactive experience. This paper does not however provide technical details of doing so. [4] Proposes AR applications as an effective way of teaching in laboratories for the students of engineering. The well-designed AR application allows students to efficiently perform a learning process without over-crowding the laboratories. This exercise greatly reduces a teacher's repetitive explanations and improves theoretical comprehension of tricky concepts like electric and magnetic fields inside electrical engines. [5] Considers the complexity of a classroom content and comes up with the development of three AR environments that are being used in regular practices now. [6] Analyzes students' learning and perception style by their interaction with puzzle games. [7] Reviews the studies done between years 2005 to 2011 regarding AR in built environment. The classification of the literature based on their concept, implementation and effectiveness enables the gaps in AR literature and proposes the directions for future study. [8] Proposes a combination of probeware and AR environment as an approach to ecosystem science learning. [9] Proposes the use of EMTs (educational magic toys) that use AR with toys for children to enhance their imagination and early learning. [10] Presents an e-learning system (ARIES) that enables the domain experts to diligently involve in authoring interactive educational scenarios. [11] Discusses the advancement of mobile augmented reality over the past years. This includes the transformation of physical devices, wearable AR and evolution of AR on mobile devices. [12] Discusses the impact of AR technology as a strong factor in the growth of confidence and attention gaining in students. In [13], the discussion goes into comprehensive description of the growth of AR technology since 1997. This paper also discusses AR displays and their limitations. The aim of the study in [14] is to give a working description of AR with both negative and positive aspects and how can it be implanted in outdoor settings. The paper also discusses the challenges presented by AR and suggestions for future implementation. [15] Proposes that implementation of augmented reality in science/physics laboratories can efficiently improve the skills and attitude towards lab work in students. [16] Encourages to embed AR lessons in STEM and claims through a practical observation that this can increase the authenticity in results and also can trigger students' perception towards STEM. [17] Suggests that AR technology can be employed to promote performance stability in sleep deprived circumstances. The study in [18] is based on the children with autism spectrum disorders that makes them face difficulty in recognizing facial expressions. A gamebook using AR is prepared as a key to grab their attention and result in better recognition of emotion and expressions. [19] Implies that inquiry based activities and Augmented Reality based mobile learning proves to be motivational for students. [20] Gives a review of systems around the world that are being successfully implemented and use AR environment to train for emergencies. It also proposes a need to combine the awareness and training together in a system for improving emergency response. [21] Proposes a system of tracking in augmented reality using a head unit and an ultrasonic wand. Furthermore it speaks about the lacking in the current system for any future work to be done on. [22] Discusses a summary of research trends and opportunities for implementing AR in the fields of architecture, engineering, construction and facility management. The study particularly focuses on localization technology, cloud computing, natural user interface and mobile devices and how their advancement can increase the usability of AR in complex environments. [23] Evaluates the effect size of AR learning experiences. The aim of the study is to inform the design of future ARLEs. [24] Proposes an authorizing tool using augmented reality for education in contrast to hard-coding methods. [25] Bases the study on using augmented reality technology in medical training. The aim of the study here is to carry out a research on extent of augmented reality based application being used currently in medical trainings. The study includes their validation and required future work. [26] Presents an in-progress project framing an AR game that is designed for pre-school aged children to improve and practice print-based literacy. [27] Presents evaluation of four techniques for annotation considering it as an important factor in AR user interface. The rate of update of annotations as per satisfaction of the user is also taken under consideration. [28] Bases the study on implementing augmented reality in neurosurgery. A review has been given of the systems using AR neuro-navigation in clinical settings. [29] Presents a system of real time object recognition for visually impaired individuals.

Other applications.

AR is extensively being used in gaming. It has also been implemented in various areas and different walks of life, such as architecture, construction sites, military, firefighting, health and safety, retailing, industries and marketing etc.

III. IMPLEMENTATION METHODOLOGIES

This section discusses the fundamental set of lab equipment commonly used by students and implemented in this application. For demonstration, Analog and Digital Communication kits have been considered in this research. This section also provides the details pertaining to the hardware and software used in the development of interactive AR environment.

A. *System Specifications*

The specifications of the workstation on which this research was carried out are given in Table I.

TABLE I
SYSTEM SPECIFICATIONS

Windows edition	Windows 10 Home Single Language
Processor	Intel(R) Core(TM) i7-4510U CPU @ 2.00GHz 2.60GHz
Installed memory (RAM)	4.00 GB (3.89 GB usable)
System type	64-bit Operating System, x64-based processor

B. Unity 5.5.0

Unity is a game development engine introduced by Unity Technologies and can be used to develop video games for PC, consoles, mobile devices, VR/ AR or websites in 2D as well as 3D since it allows for cross-platform implementation. Unity 5.5.0 is used in this research and the language used for scripting is C#. Some assets used in this research have been taken from the unity asset store while others have been designed.

C. Vuforia

Vuforia is an AR software development kit (SDK) for devices that support the development of Augmented Reality applications. It basically detects markers using Computer Vision Technology and the markers can be planar images or simple 3D objects in real time. This facility enables the user to place and position virtual objects and 3D models in reference with the target image so that when observed through a mobile device camera, the virtual object finds its oriented place on the reference image hence making itself appear as a part of the real scene.

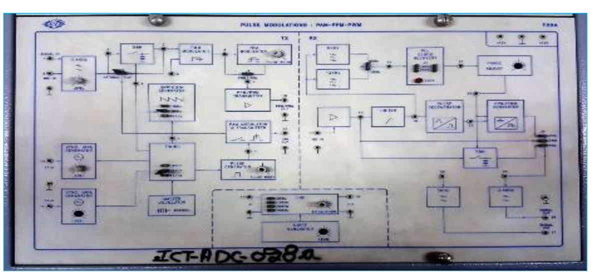
1) *image target "star-rating" limitations*
The star rating of the image to be used as a target should be 4-5 stars for best results. Low star-rated image does get identified by the system but its best to increase system's accuracy. The marker should have good contrast, be rich in detail and not have any repetitive patterns in order to get high star-rating [30].

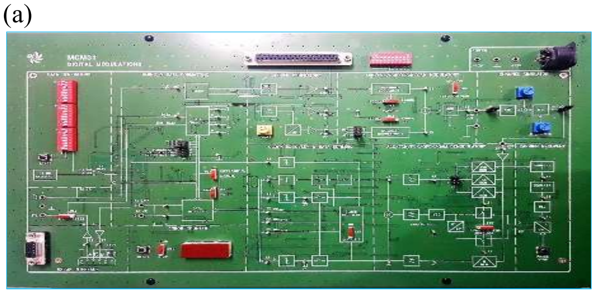
D. Lab Trainer Kits
The application has been designed to convert an entire course lab to AR based implementation. The course used for this deployment is Analog and Digital Communications (ES342). The lab trainer kits used in this research have been designed by ElettronicaVeneta (EV) and are discussed in the following sections.

1) *T20A pulse modulations*
This kit offers experiments on various pulse modulations techniques including Pulse Amplitude Modulation (PAM), Pulse Width Modulation (PWM), Pulse Position Modulation (PPM) and Pulse Code Modulation (PCM), as shown in Fig.1 (a).

2) *MCM31 digital modulations*
MCM31 offers experimentation with generation, channel simulations and demodulation of various Digital Modulation schemes such as Amplitude Shift Keying (ASK), Frequency Shift Keying (FSK) and Phase Shift Keying (PSK), among others. This module is shown in Fig. 1 (b).

3) *T10B amplitude modulation*
This kit offers practical demonstrations pertaining to Amplitude Modulation (AM), along with Double Sideband Suppressed Carrier (DSBSC) and Single Sideband Suppressed Carrier (DSBSC). The T10B module is shown in Fig. 1 (c).


(a)


(b)

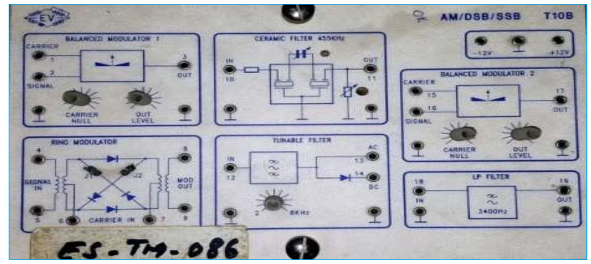

(c)

Fig. 1. Lab Trainer Kits (a) T20A Pulse Modulations (b) MCM31 Digital Modulations (c) T10B Amplitude Modulation

E. Mobile Devices
Unity provides a powerful feature that allows developers to design a single application and build it for various platforms including android, iOS, Windows phone etc. as shown in Fig. 2.

Fig. 2. Cross-platform mobile app development

The mobile phones used for testing and debugging in this research along with their specifications are given in Table II.

TABLE II
MOBILE PHONE SPECIFICATIONS

S. No.	Hand Phone	Processor (GHz)	RAM (GB)	Rear Camera (MP)	OS
1	Samsung Galaxy Grand Prime	1.2 (Quad-core)	1	8	Android v4.4 KitKat
2	Samsung Galaxy S6	2.1 (Octa-core)	3	16	Android v5.0.2 Lollipop
3	Infinix Hot 4	1.3 (Quadcore)	2	8	Android v6.0 Marshmallow

F. Experimental Setup

The setup consists of a handheld smart gadget with a camera and an operating system out of the many supported by Unity as shown in figure 3. It also includes the kits, which act as markers for audio/ visual augmentation of guidelines for students to assist them in learning proper use of lab equipment. The markers used here and the ratings scored by them at Vuforia are shown in Fig. 3.

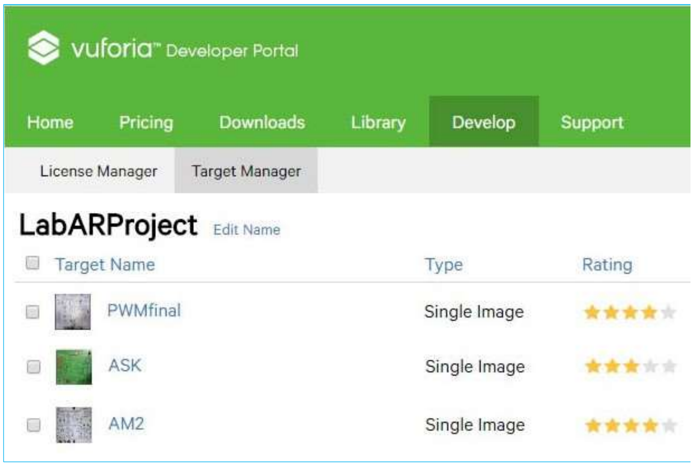


Fig. 3. Vuforia markers' ratings

G. Proposed Algorithm

The application consists of 4 sections combined together. The algorithms of each section are given in Fig. 4. The block diagram of the complete system is given in Fig. 5.

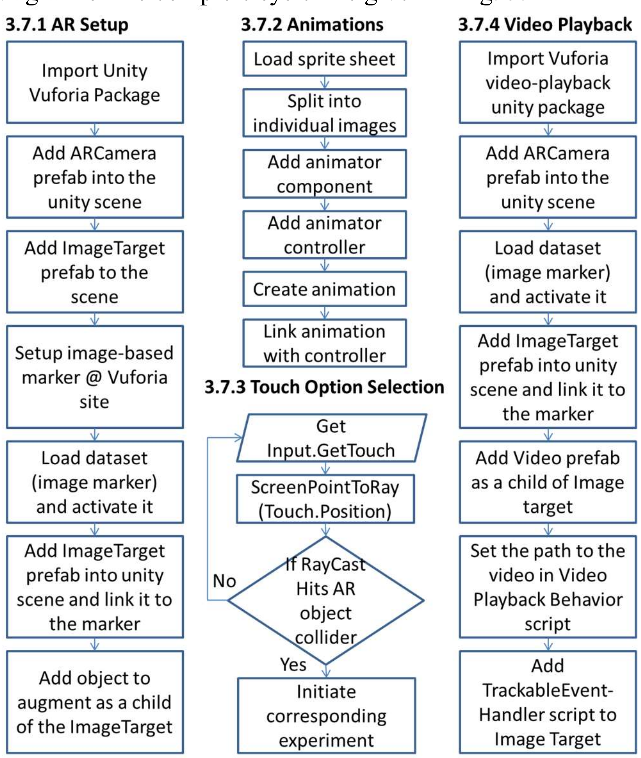


Fig. 4. Algorithms of individual sections

IV. RESULTS AND DISCUSSION

This section provides the results of various sections of this application, along with the complete system results. It also covers the discussion pertaining to the accuracy and efficiency of the developed application, along with optimum operating conditions. Student feedback is also provided here.

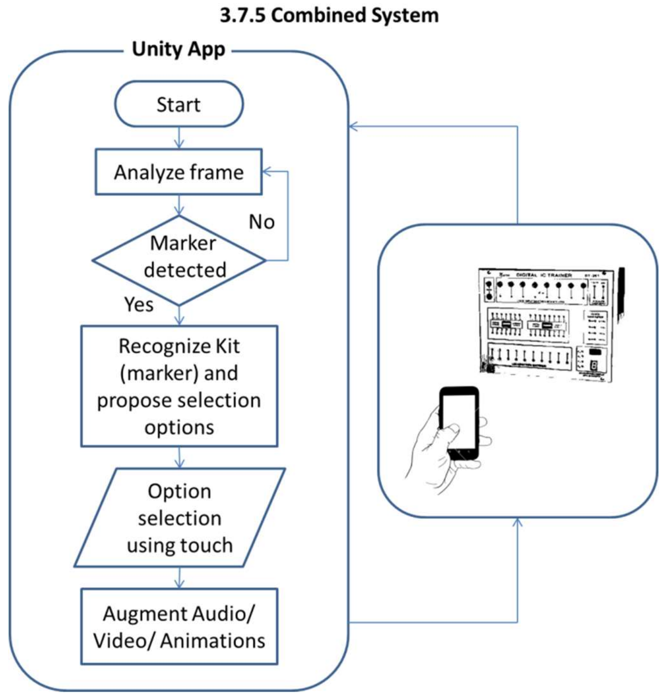


Fig. 5. System block diagram

A. AR Setup

An AR camera is *used* here in the unity scene instead of the conventional camera as shown in Fig. 6. The license and the image target database (marker) are acquired from vuforia developer portal's license manager and target manager respectively, and plugged into unity. This image target is later used as a marker for augmentation of guidelines for students whenever this kit is placed in front of a smart phone's camera running this app.

Fig. 6. AR marker in Unity scene

B. Animations

The sprite sheet used to generate animation indicating power supply connections in the kits is given in Fig. 7. This sheet is split into individual arrow images (cell count: 10x10) which are later changed with respect to time at a frame rate of 50 fps to produce the animating arrow effect.

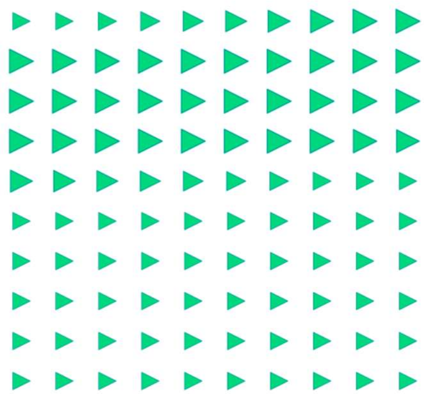


Fig. 7. Sprite sheet

C. Option Selection Using Touch

Upon detection of marker, which in this case is the lab equipment, different experiment options offered by that particular kit are displayed, as shown in Fig. 8. Any of the proposed options can be selected by touching it. Once identified the option touched by user, corresponding experimental setup is augmented over the kit. This includes power supply inputs, wire connections, jumper settings, switch settings and input/ output waveform videos, which is given in section E.

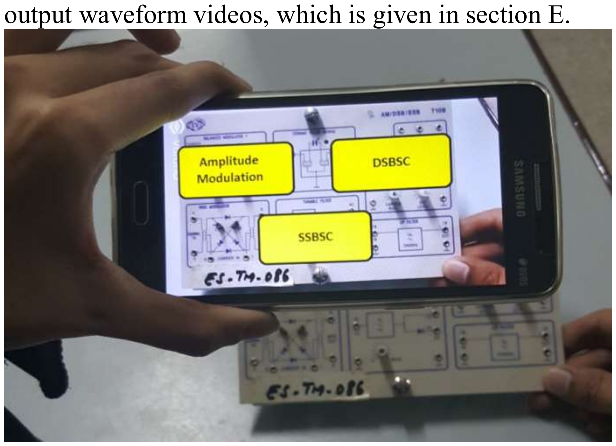


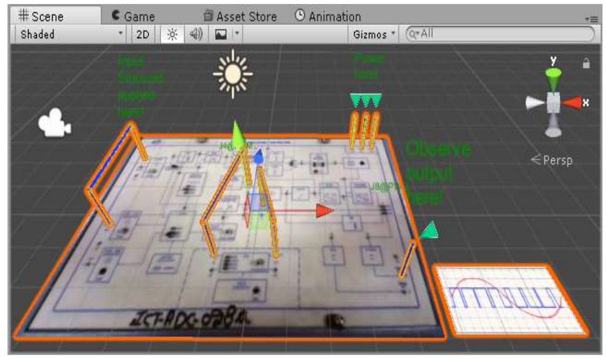
Fig. 8. Experiments offered by the kit T10B

D. Video Playback

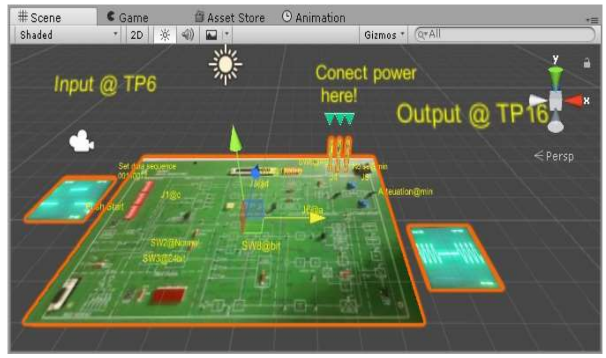
The applied inputs and expected outputs of the kits have been augmented in the form of videos. These videos can be controlled (played, paused or stopped) by the students.

E. Combined System

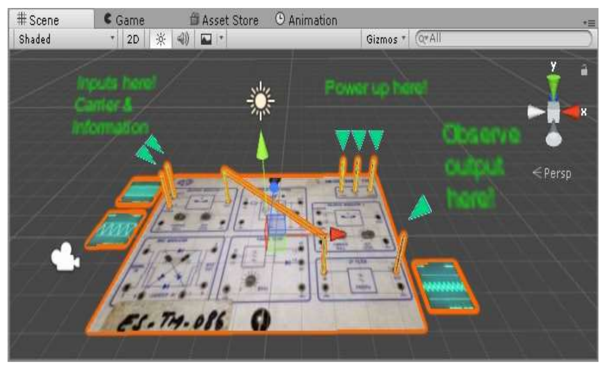
after the completion of all the design parameters (shown in Fig. 4 & Fig. 5) in unity, the final stage is to build an app using any of the platforms supported by unity. These platforms include PC, Mac and Linux standalone, iOS, tvOS, Android, Tizen, Windows Store, WebGL, Samsung TV and Xbox One among others. Figure 9 shows the Unity scenes of combined system design for T20A, MCM31 and T10B and the results of the app built for android smart phone are given in Fig. 10.



(a) T20A



(b) MCM31

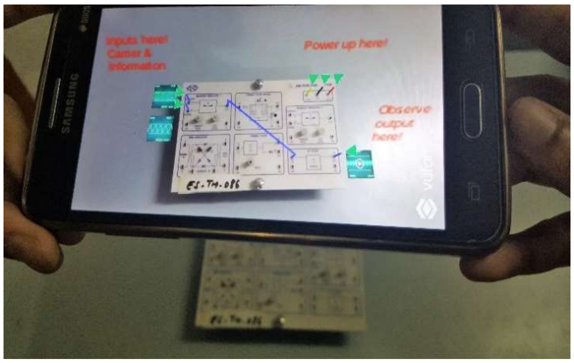


(c) T10B

Fig. 9. Unity scenes of combined System

(a) T20A

(b) MCM31



(c) T10B

Fig. 10. Results

F. Optimum Operating Conditions

Various tests were performed to analyze the optimum operating ranges of the application with respect to parameters like light intensity, distance and angle between the mobile device and the lab equipment, as shown in Fig. 11. The results are provided in Table III.

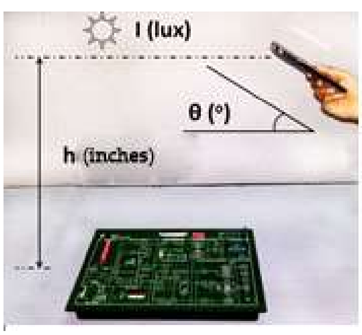


Fig. 11. Parameters used in analysis of optimum operational limits

TABLE III
OPTIMUM OPERATING RANGES

S. No.	Parameter	Minimum	Maximum
1	Light intensity (lx)	48	13K
2	Distance (inches)	30	55
3	Angle (Degrees)	0	30

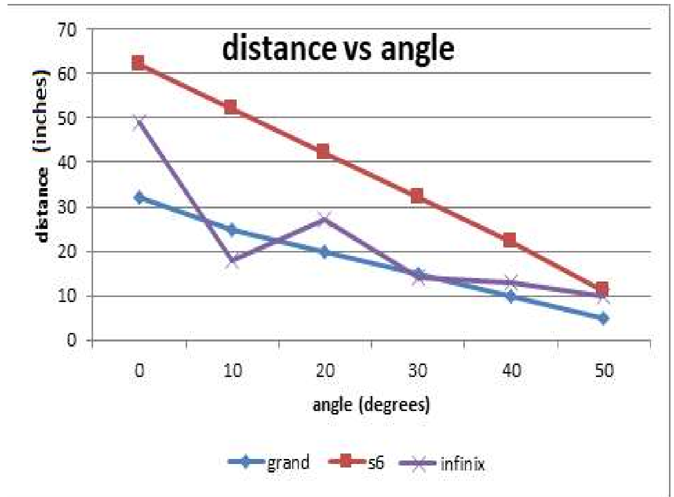


Fig. 12

G. Accuracy

The accuracy of this system can be computed in terms of marker recognition rate of the app. If the rating provided to the marker by Vuforia is greater than 3 stars, as shown in Fig. 3, then the accuracy of the marker detection by the system is very high. The number of recognitions offered by this app during testing and experimentation are given in Table V.

TABLE V
SYSTEM ACCURACY

S. No.	Marker No.	Vuforia rating	Recognition attempts	Accuracy
1	1 (Figure 1a)	4 stars (Figure 3)	50	100%
2	2 (Figure 1b)	3 stars (Figure 3)	50	100%
3	3 (Figure 1c)	4 stars (Figure 3)	50	100%

H. Student Feedback

The feedback of a section of final year students was acquired for the developed app and the rating achieved on a star based rating system is shown in Fig. 13.

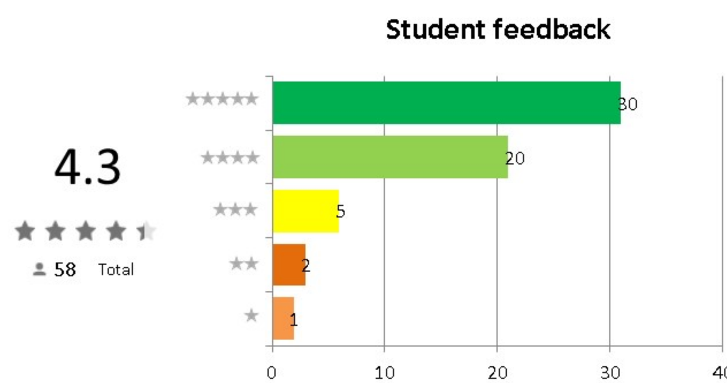


Fig. 13. Student feedback

V. CONCLUSION AND FUTURE RECOMMENDATIONS

This app proved to be an interesting and interactive replacement of conventional lab manuals to assist students in handling lab equipment and training kits. In this study, the developed app was successfully deployed on the lab work of an entire course of Analog and Digital Communications (ES342) with an encouraging student feedback. An extension of this work on head-mounted equipment like Google Glasses or Microsoft Hololens can greatly increase the flexibility for students, as a hand-held device can cause hindrances in robust equipment handling. Furthermore, as an extension of this work, all the lab-based courses of Electronics Engineering can be converted to AR for ease of students and lab instructors.

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